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50TH ANNIVERSARY OF THE CENTRAL INSTITUTE OF AEROHYDRODYNAMICS IMENI N.YE. ZHUKOVSKIY

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50TH ANNIVERSARY OF THE CENTRAL INSTITUTE OF AEROHYDRODYNAMICS IMENI N.YE. ZHUKOVSKIY

Academician M.D. Millionshchikov

ABSTRACT: The author describes the development of aircraft, aerodynamic and hydrodynamic studies at the Central Institute of Aerohydrodynamics imeni N.Ye. Zhukovskiy from its founding in 1918 to the present. The problems encountered in the studies, and the successful solutions and achievements are described.

A half a century ago, in December of 1918, the Central In-   /34*
stitute of Aerohydrodynamics - the TsAGI - was founded under the
instructions of V.I. Lenin. This institute was organized on the
initiative of one of the greatest scientists of these times -
N.Ye. Zhukovskiy, whose name it now bears.

The TsAGI was one of the first institutes of a new type. As
is well known, the State Institute of Optics, the Physicotechnical
Institute of the Academy Sciences of the U.S.S.R., the Scientific-
Research Physicochemical Institute imeni L.Ya. Karpov, and a number
of other establishments which would be the principal grounds for
the development of the corresponding fields of science and tech-
nology were also organized during these difficult years of Soviet
government. The TsAGI was entrusted with the task of working out
the scientific principles for the development of aviation and other
branches of technology, for which such branches of applied mechanics
as aerodynamics, hydrodynamics, strength and solid-state dynamics
also had a determinant value. During the initial period, in addi-
tion to the scientific problems, the Institute studied the design
and construction of experimental aircraft. This problem was solved
successfully under the direction of A.N. Tupolev.

The studies carried out in the TsAGI were the scientific basis
for the development of Soviet aviational, rocket and space tech-
nology. Both in the theoretical aspect and in the applications to
the problems of aircraft technology, they were directed mainly to-
ward the development of three main divisions of mechanics - aero-
hydrodynamics, dynamics and strength.

Aerodynamics and Dynamics. The studies in the field of the
mechanics of fluids and gases carried out by the scientists of the
TsAGI were always subject to problems connected with streamline

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* Numbers in the margin indicate pagination in the foreign text.

flow around bodies and internal flows at various velocities. The
successful solution to these problems became the grounds for the
development of the applied divisions of aerodynamics: the aero-
dynamics of the wing and rotor, the aerodynamics of aircraft and
rockets, experimental aerodynamics, etc. For the development of
such divisions of aircraft dynamics as stability and controllability,
the control systems and trajectory dynamics, an analysis of the
problems of general mechanics and the theory of control processes
became a fundamental task.

The rapid increase in flight speeds which is characteristic
of aviational, rocket and space technology gave rise to the need
for using various models of the flow of a fluid and gases in aero-
dynamics. The modeling methods for experimental investigations
were worked out in correspondence with this.

Subsonic Speeds. During the beginning period of the develop-
ment of aviation, when the aircraft were equipped with piston
engines, even the maximum flight speeds did not exceed 40-50% of
the speed of sound, which eliminated the effect of the compress-
ibility of the air and gave way to an intensive study of the stream-
line flow of an incompressible fluid.   /35

N.Ye. Zhukovskiy
(1847-1921)

The classic studies of N.Ye.
Zhukovskiy and S.A. Chaplygin, which
treated the connections between the
lift of a wing with circulation of
speed around the profile - a condi-
tion determining the magnitude of
the circulation - and a wing design
with a system of connected vortices,
were fundamental for the development
of this division of aerodynamics.
N.Ye. Zhukovskiy and S.A. Chaplygin
also developed an accurate theory of
the streamlining an ideal flow of an
incompressible fluid about aerodynam-
ics profiles of a particular type.
This theory was the starting point
for many other studies at the TsAGI.
It was extended to the case of multi-
parametric profiles, and it aided in
establishing the general properties
of multiply-connected contours, in
giving closed solutions to the pro-
blems of their streamline flow, and
in presenting the principles of the
nonlinear theory of the streamline
flow of plane bodies with jet escape
(M.V. Keldysh, V.V. Golubev, A.I. Nekrasov, M.A. Lavrent'yev, L.I.
Sedov).

The method of solving the problem of the streamlining of plane
contours with the aid of integral equations (M.A. Lavrent'yev) de-
veloped in the 1930's recently became the basis for the solution
to nonlinear problems of the streamlining of plane and three-dimen-
sional bodies analyzed on digital computers. The approximating
methods of calculating the streamlining of wing profiles and re-
volving bodies by an incompressible fluid constructed by scientists
of TsAGI played a great rule in the future in the practice of aero-
dynamic designing (Ya.M. Serebriyskiy, L.A. Simonov, N.I. Sharokhin,
etc.).

Studies in the field of the theory of a wing of finite span
had a specific technological directionality which required the
development of calculation methods suitable for direct technolog-
ical application.

The first studies in this field treated the construction of
practical approximation methods for solving an integro-differential
equation for a wing of finite span (B.N. Yur'yev, V.V. Golubev,
A.B. Risberg), as well as the general properties of the integro-
differential equation (M.V. Keldysh, G.I. Maykapar).

The study of the streamlining around bodies of an incompress-   /36
ible viscous fluid brought about the development of the boundary-
layer theory. A method of approximating integral relationships
was established for a laminar boundary layer in the case of steady
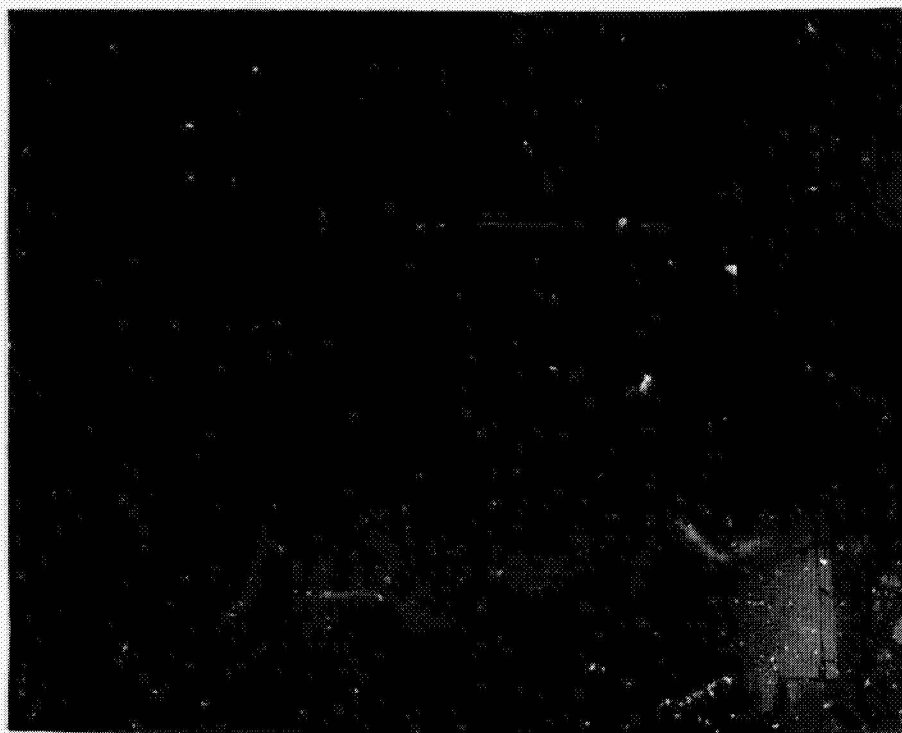
Full-Scale Wind Tunnel for Studies of Aircraft, Large-
Scale Models, Engine Systems and Flutter Tests

and unsteady motion (N.Ye. Kochin, L.G. Loytsyanskiy, V.V. Strum-
inskiy). The steadiness of motion of a viscous fluid was also
investigated in an exhaustive manner (G.I. Petrov).

The rules for the arisal of a uniform isotropic turbulence
were established. Works on the study of the attenuation of veloc-
ity pulsations were the basis for the development of low-turbulence
wind tunnels (M.D. Millionshchikov). Experimental examinations of
turbulent flows, the transition of a laminar boundary layer into
a turbulent one, and the corresponding changes in aerodynamic
characteristics of streamlined bodies aided in obtaining flows
with substantial expansion of the laminar-layer region and a great
decrease of the frictional resistance (G.P. Svishchev, I.V. Osto-
slavskiy, K.K. Fedyayevskiy, A.S. Ginevskiy).

The theory of a propeller on an incompressible fluid, the
original prerequisites for the design of which were given by N.Ye.
Zhukovskiy in 1912, was further developed at the TsAGI. The methods
of calculating and designing them were constructed on the basis
of the rotational system of a propeller with an infinitely large
number of blades (V.P. Vetchinkin, G.I. Kuz'min). The scientists /37
at TsAGI used the vortex systems for designing single propellers
with a finite number of blades and for coaxial propellers (N.N.
Polyakhov, A.M. Lepilkin, G.I. Maykapar, D.V. Khalezov, V.V. Keldysh,
B.P. Blyakhman), as well as for the lifting rotors of helicopters
(B.N. Yur'yev, G.I. Maykapar, A.I. Slutskiy, L.S. Vil'dgrube,
V.E. Baskin).

Large Variable-Density Wind Tunnel of Subsonic and Tran-
sonic Velocities with Perforated Walls (View Against the
Flow)

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Applied aerodynamics developed in connection with a search for ways of decreasing the head resistance of an aircraft: gathering in the alighting gear, improving the shapes of the fuselage and other elements of the aircraft, introducing special systems which improve the cooling of the engines and have low head resistance (K.A. Ushakov, V.G. Nikolayenko, A.K. Martynov, S.L. Zak, A.I. Sil'man), and pressurization of the entire aircraft (I.V. Ostoslavskiy, Ye.I. Kolosov).

Among the most important problems solved by the Institute, there was the designing of experimental equipment and the development of scientifically sound methods and techniques for the experiment. The TsAGI was equipped with first-class laboratories and wind tunnels. A new aerodynamic center with wind tunnels which could test aircraft on full scale (B.Ya. Kuznetsov, K.N. Surzhin, S.S. Sopman, K.K. Baulin, K.A. Ushakov, B.A. Ushakov, G.M. Musinyants) and with devices for studying the strength of aviational structures was founded in 1934-1939.

At the beginning of the 1940's, combat aircraft which had rather low resistance were constructed as a result of studies carried out on full-scale tunnels. The studies on full-scale tunnels aided in increasing the flight speeds of aircraft and improving their navigation characteristics and take-off-landing qualities during World War II.

Fundamental investigations of the wing theory and numerous experiments allowed scientists to propose the principles of the aerodynamic design of a high-stability wing for large angles of attack at the beginning of the 1940's (A.B. Risberg, P.P. Krasil'shchikov, F.G. Glass); this made it possible to increase the safety of flights to a great extent.

In the field of flight dynamics, one of the most important problems of guaranteeing a safe recovery from a spin was solved (A.N. Zhuravchenko, V.S. Pyshnov, Ye.A. Pokrovskiy), and a system of criteria for selecting the requisite stability and controllability characteristics was constructed (V.N. Matveyev, Ye.I. Kolosov, M.L. Mil'). Methods of calculating the stability and controllability of an aircraft with effective propellor were constructed on the basis of studies on full-scale wind tunnels.

The result of studies at the TsAGI in the field of applied aerodynamics of an aircraft for a specified range of flight speeds was the basic theme of the "Rukovodstvo dlya konstruktorov" (Manual for Designers), which was published in 1943, and which contained the principal materials of experimental studies, calculation methods and aerodynamic designing of an aircraft.

Transonic Speeds. During the end of the 1930's and the beginning of the 1940's, the need for developing theoretical and experimental studies in the field of the aerodynamics of a com-

pressible fluid arose in connection with the increasing requirements
imposed on the speeds of aircraft. Among the first studies of the
Institute in this new field, we should name the generalization of
Zhukovskiy's theorem for the case of a compressible gas for sub-
sonic flight speeds (M.V. Keldysh, F.I. Frankl'). The theory was
developed, and the methods were constructed, for calculating the
streamlining of a profile at high subsonic speeds; the former were
based on the idea proposed at the beginning of the XXth century by
S.A. Chaplygin, concerning the linearization of equations of motion
of a gas by transferring to the plane of the velocity hodograph
(S.A. Khristianovich). There also appeared theoretical studies
which clarified the properties of transonic gas flows (F.I. Frankl',
A.A. Nikol'skiy, G.I. Taganov).

Important works on the development of the theory and the con-
struction of methods for calculating the boundary layer in a com-
pressible gas were carried out at the TsAGI parallel with the study
of the dynamics for motion of a nonviscous gas. The transformation
which reduces this problem to mathematically equivalent equations
of the boundary layer in an incompressible fluid (A.A. Dorodnitsyn)
played the determinant role here.

The establishment of rules for flows at subcritical and super-
critical speeds, and the development of aerodynamic designs of
aircraft satisfying the stability, controllability and flight safety
requirements, became possible because of the variable-density tran-
sonic-velocity wind tunnel constructed at TsAGI (S.A. Khristianovich,
G.N. Abramovich, M.V. Glazer, I.P. Gorskiy, S.A. Dovzhik, A.P.
Kovalev).

The studies of transonic flows were expanded radically in 1947,
when a wind tunnel with perforated walls in the effective part,
which allowed experiments with continuous transition through the
speed of sound, was set to work at TsAGI (S.A. Khristianovich, S.A. <u>/39</u>
Aristarkhov, B.V. Belyanin, V.G. Gal'perin). Subsequently, im-

$$\bar{c}_x = \frac{c_x}{c_x(m < \mu R)}$$

Relative change in head resistance
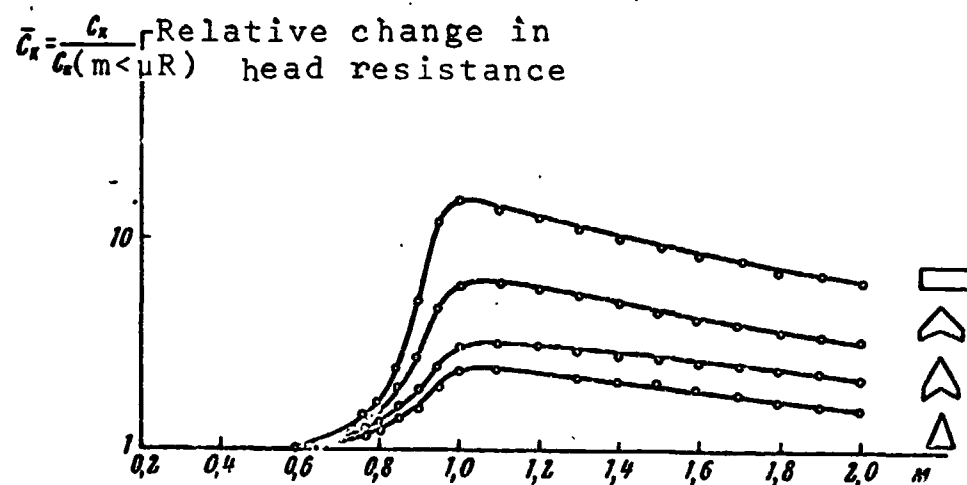
Effect of Wing Shape on Shock Drag in Transition to
Supersonic Flight Speeds

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portant properties of perforated boundaries with 50%-penetrability were discovered - the ability to quench strong disturbances and eliminate nonuniformity in a supersonic flow (G.P. Svishchev, G.L. Grodzovskiy, A.A. Nikol'skiy, G.I. Taganov).

Extensive experimental studies brought about the establishment of a number of properties of transonic flows with local supersonic zones, e.g., the properties of stabilization of local Ma numbers on isolated profiles (S.A. Khristianovich, V.G. Gal'perin, I.P. Gorskiy, A.P. Kovalev) and profiles with rudder and aileron (G.P. Svishchev). The properties of flows due to the simultaneous effect of compressibility and viscosity of the air and the disturbing substantial changes in aerodynamic characteristics were also studied.
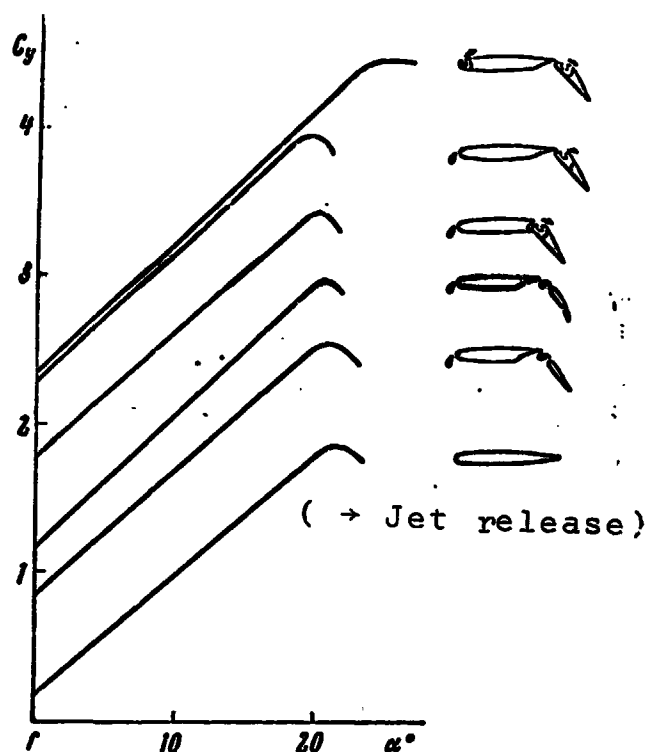
All the studies carried out aided in constructing the methods for aerodynamic calculation of profiles and for obtaining those shapes of the latter for which the development of a shock stall was displaced in the range of greatest possible speeds (P.P. Krasil'shchikov, G.P. Svishchev, Ya.M. Serebriyskiy, M.V. Ryzhkova and R.I. Shteynberg). Subsequently, aerodynamic arrangements of wings designed for high subsonic flight speeds were developed. The wings of these native aircraft began to be designed solely from the wing profiles of TsAGI.

Great importance in the activity of TsAGI was given to the study of the aerodynamic propellers of aircraft. The construction of the theory of a propeller with an infinitely large number of blades in a compressible medium began in 1936; in 1942, the theory of a propeller with a finite number of blades was developed (F.I. Frankl'). Experimental studies were carried out in order to explain the effect of compressibility (D.V. Khalezov, B.P. Blyakhman), particularly on drained propellers (G.I. Maykapar, V.V. Keldysh, V.I. Ganabov). As a result of these studies, highly-effective propellers were designed for the TU-114 and AN-22 aircraft with propjet engines (D.V. Khalezov, B.P. Blyakhman, S.L. Belkin, and others).

The application of jet engines, which permitted obtaining velocities close to the speed of sound, was an important step in the development of aviation. This brought about the transition to arrowhead and thin wings of small span which had less wave drag and the requisite stability characteristics. The theory of the lifting line was expanded for the case of a slip wing with a thin fuselage (A.A. Dorodnitsyn), and a simplified method for practical /40 design of a swept wing was proposed (V.V. Struminskiy, N.K. Lebed'). Numerical methods for designing wings of the present shapes were constructed on the basis of the airfoil theory (P.I. Chuskin, G.A. Kolesnikov, S.M. Belotserkovskiy, and others).

Supersonic Speeds. In the transition of aviation to supersonic flight speeds, the TsAGI met up with a number of new problems.

One of them was the development of the theory of supersonic gas
flows which differ in their properties from subsonic ones. A solu-
tion to this problem required investigations of differential equa-
tions which describe supersonic flows and the development of gen-
eral methods for integrating them (F.I. Frankl', S.A. Khristianovich).

An analysis of three-dimensional
supersonic gas flows around wings
and bodies of different configura-
tions was the most complex task
from the theoretical point of
view and the most important in
practical aspect. As a result
of the studies which were carried
out, a number of new and precise
solutions were obtained for gas-
dynamical equations (A.A. Nikol'
skiy). A fruitful method for
approximative integration of the
equations of characteristics was
proposed for axisymmetric gas
flows around rotating bodies
(A.A. Dorodnitsyn), which also
used the streamlining of rotating
bodies at angles of attack for
the calculations (V.V. Sychev).

The scientists of TsAGI also
solved a number of problems in
the field of the theory of a wing
of finite span (S.C. Fal'kovich,
M.I. Gurevich, V.M. Shurygin,
M.F. Pritulo) and other lifting

(→ Jet release)

Increasing the Lift by Mech-
anization of the Wing and Bound-
ary-Layer Control.

systems (G.I. Taganov) in a supersonic flow.

A new approach to the solution of problems of finding the op-
timal aerodynamic forms using a record of the variation condit
for the end characteristic of the surface was found to be very
fruitful (A.A. Nikol'skiy). This approach was subsequently use.
to a great extent in order to solve many problems concerning wings
and rotating bodies with minimum drag (M.N. Kogan, V.N. Zhigulev, /41
Yu.L. Zhilin).

Theoretical and experimental studies in the field of supersonic
aerodynamics guaranteed the successful accomplishment of a number
of studies directed toward the construction of aerodynamic designs
for supersonic aircraft of different types. Thin delta wings and
large sweptback wings were used for supersonic aircraft in order
to make a great decrease in the shock drag, and in order to guar-
antee a smooth change in all the basic aerodynamic characteristics
(including the characteristics of stability and controllability in
transitions through the speed of sound) (V.V. Struminskiy, G.S.
Byushgens, G.V. Aleksandrov, K.K. Kostyuk, P.P. Krasil'shchikov,

K.F. Petrov, T.I. Okerblom, N.K. Lebed', Ya.M. Serebriyskiy, V.M. Shurygin).
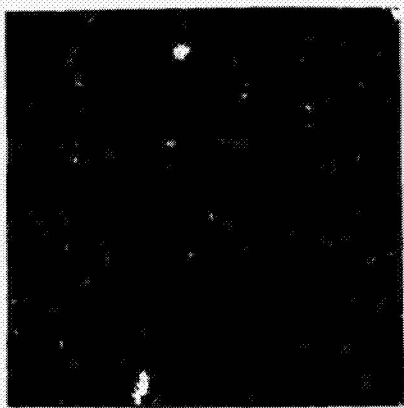
Streamlining of
Aircraft Model at
Supersonic Speeds.

The new shapes of thin, small-span wings with complex configuration in design and deformation of the middle surface proposed subsequently by scientists of TsAGI (R.I. Shteynberg, L.Ye. Vasil'yev, A.A. Gladkov, M.F. Pritulo and others) were the basis for the arisal of supersonic passenger aircraft. The results of the studies of the Institute brought about the first-class machines made by the construction department headed by S.V. Il'yushin, A.I. Mikoyan, P.O. Sukhiy, A.N. Tupolev, A.S. Yakovlev and others.

Theoretical and experimental works on the interference of a wing with fuselage and engine pods, carried out by imposing fields of disturbances in order to determine the most suitable forms of connection of these elements and in order to improve the aerodynamic characteristics of high-speed aircraft, had great significance (G.P. Svishchev, V.S. Polyadskiy, R.I. Shteynberg, K.K. Kostyuk, G.L. Grodzovskiy, V.V. Keldysh).

The TsAGI developed and investigated a highly-effective mechanization of an aircraft wing in the form of droop flaps and multislotted external-airfoil flaps and systems of boundary-layer control (P.P. Krasil'shchikov, K.P. Petrov, G.A. Yudin, Ya.M. Serebriyskiy), and it suggested control organs - rudders, ailerons and ailevators (A.B. Lotov, A.Zh. Rekstin, V.T. Zhdanov, V.G. Mikeladze), which could be used on practically all the native aircraft.

The development of jet aviation raised a number of new scientific problems in the gas dynamics of internal flows. Methods of solving such problems were proposed at TsAGI for flows in channels with variable cross section, flows with consideration of friction, with supply of thermal and mechanical energy, etc. (S.A. Kristianovich, V.G. Gal'perin, M.D. Millionshchikov, L.A. Simonov).

Works on the theory and methods of calculating bodies with a canal and air intakes with effective deceleration of the supersonic flow (A.V. Nikolayev, V.G. Nikolayenko, G.I. Taganov, N.I. Sharonin, V.G. Gurylev) were developed in particular, as were studies on the problems of the interaction of flows in aircraft channels and a jet /42 engine compressor (A.G. Kukinov). Jet machines of a new type - supersonic compressors - were designed (Yu.N. Vasil-yev, Yu.G. Zhulev).

During the period of the design of supersonic aircraft, a number of new criteria and calculation cases concerning the stability

and controllability were established. The effect of large Mach
numbers on the characteristics of lateral stability was found to
be particularly substantial. New calculation methods aided in
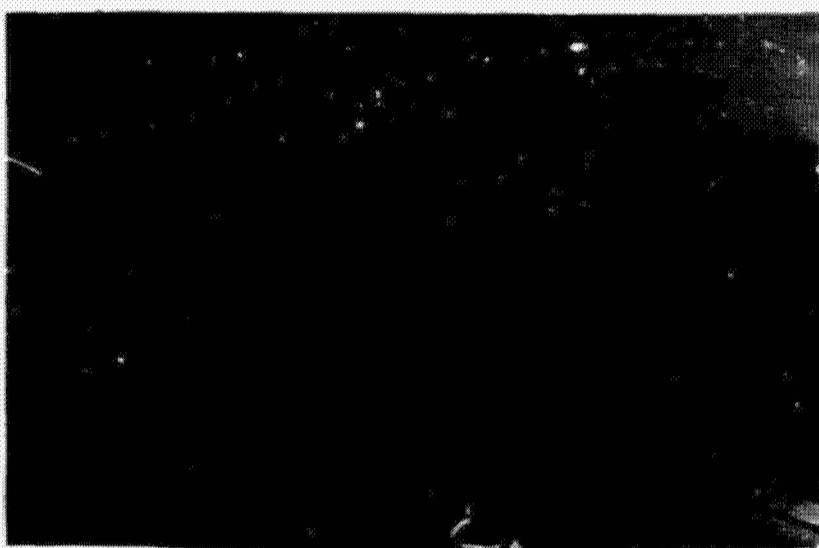
Hypersonic Wind Tunnel with Electric-Arc Gas
Heating.

determining the relationship between the rolling and yawing motions
and the inertial interactions between the lateral and longitudinal
motion for abrupt rolling (G.S. Byushgens, G.V. Aleksandrov, R.V.
Studnev). The flights of aircraft at high speeds also required the
development of principles for booster control (Yu.A. Boris, V.N.
Matveyev, A.I. Kur'yanov).

The large supersonic-velocity wind tunnels constructed at TsAGI
at the end of the 40's and later (S.A. Aristarkhov, O.V. Lyzhin,
A.T. Strel'tsov, Yu.N. Belorusov and others) made it possible to
carry out a number of investigations in order to solve general and
applied problems connected with the design of specific aircraft
models. Their construction was based on the development of such
elements as plane and axisymmetric nozzles with high uniformity of
flow (V.K. Solodkin, A.A. Nikol'skiy, I.I. Mezhirov, G.M. Ryabinkov),
regulated supersonic exit cones with a high coefficient of pressure
regulated supersonic exit cones with a high coefficient of pressure
regeneration (G.M. Ryabinkov), and single-stage and multi-stage
high-compression ejectors with high coefficients of ejection (S.A.
Khristianovich, M.D. Mi-lionshchikov, G.M. Ryabinkov, A.A. Nikol'
skiy, G.I. Taganov, Yu.N. Vasil'yev, I.I. Mezhirov, O.V. Lyzhin).

Hypersonic Speeds. The aerodynamics of hypersonic gas flows,
i.e., flows at velocities   ich greatly exceed the speed of sound,
began to develop intensively during the last decade with a further /43
increase in the velocities in a   nd, in particular, with the
development of space technolog

The contribution of Ts   s new field of mechanics also

very substantial. Here, for the first time, the theory of three-dimensional hypersonic flows around thin bodies at arbitrary angles of attack was developed (V.V. Sychev), new qualitative rules for the streamlining of blunt bodies were discovered (V.V. Sychev, M.D. Ladyzhenskiy), and the specific properties of complex bodies with compression layers and aerodynamic characteristics changing sharply in terms of Mach numbers were established (G.I. Taganov). An effective numerical method for integral relationships was proposed in order to solve a large number of gas-dynamical problems; it was the first to permit calculations of the streamlining of a blunt body with an unattached shock wave (A.A. Dorodnitsyn).

The movement of bodies at hypersonic speeds is connected with very high temperatures of gas heating in intensive shock waves and boundary layers. This results in the need for considering the corresponding changes in the thermodynamic properties and chemical composition of the gas, and raises the most important problem of studying aerodynamic heating and the development of means for heat protection of the surface of hypersonic aircraft.

A large number of theoretical and experimental studies carried out by scientists of TsAGI during the most recent period has been dedicated to these problems. We should first of all mention the series of studies on the heat transfer to the surface of bodies of various shapes in a hypersonic flow (G.I. Maykapar, V.Ya. Borovoy, M.V. Ryzhkova and others), which involves the development of new experimental methods for their determination. Theoretical studies attempting to explain the effect of the radiation of the air on the field of a hypersonic flow and the level of thermal fluxes (V.N. Zhigulev, V.Ya. Neyland, and others) had great significance. Great achievements were made in explaining the effect of the interaction of a boundary layer and an external flux on the aerodynamic characteristics of wings and bodies in a hypersonic flow (M.D. Ladyzhenskiy, V.V. Mikhaylov, V.N. Gusev), as well as the effect of the molecular structure of the gas on the aerodynamics of a hypersonic flight in the upper layers of the atmosphere (M.N. Kogan). Accurate particular solutions to the Boltzmann equation were obtained (A.A. Nikol'skiy, V.S. Galkin) and, finally, the fundamental theoretical results of studies of the motion of an ionized gas in electrical and magnetic fields were presented (V.N. Zhigulev, M.N. Kogan).

Theoretical and experimental studies in the field of hypersonic aerodynamics permitted the TsAGI to expand the search for designs of hypersonic aircraft. Special gas-dynamical devices designed for high Ma numbers and great heat fluxes were constructed for experimental studies in the field of hypersonic speeds.

The investigations of the optimal trajectories and flight regimes of aircraft of different types, based on the conditions for obtaining specified flight data, are of substantial interest (L.M. Shkadov, G.L. Grodzovskiy, Yu.N. Ivanov, V.A. Il'in).

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Studies on a Ballistic Tube.

Hydrodynamics. A hydrodynamic laboratory was organized at TsAGI at the end of the 1920's, and in 1930 a unique experimental basin – a "water channel" – was constructed. /44 During these years, the plane problems of the skimming of a plate over the surface of a weightless (S.A. Chaplygin, M.I. Gurevich and A.R. Yanpol'skiy) and a heavy (N.Ye. Kochin, L.I. Sedov) fluid were solved, and extensive strdies of the steadiness in gliding of seaplanes were carried out (L.A. Epshteyn). The problem of the impact of a solid body to a number of problems concerning the impact to plane plates, a floating panel, etc. were obtained (M.A. Lavrent'yev, M.V. Keldysh, L.I. Sedov, A.I. Markushevich).

Intensive studies on the problem of submerged wings also began then; they showed a number of particular features in their characteristics, particularly the effect of the depth of submersion and the break of the atmospheric air, which results in a decrease in the lift and a loss in the steadiness of motion (A.N. Vladimirov, V.G. Frolov, L.A. Epahteyn). An approximating theory of submerged wings was developed at the same time. A new effective method of studying the wave motion of a weighable fluid made it possible to

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study a number of problems of the skimming, vibration of bodies below the water, and the theory of waves on the surface of a heavy fluid (M.V. Keldysh, N.Ye. Kochin. L.I. Sedov).

During World War II, the Institute carried out studies on the hydrodynamics of ships, formulated a hydrodynamic theory of rocking (M.D. Khaskind), and solved the problems of the drag of boats, windward banking, the hydrodynamics of rudders, diesel propellers and their interaction with the body.

The scientists of TsAGI carried out studies in the 1940's which treated the arisal of cavitation, obtained an approximating equation for the expansion of the cavity contour, and proposed the "principle of independence of cavity expansion" (G.V. Logvinovich, L.A. Epshteyn). Later (middle of the 50's), a number of problems concerning the rapid entry of bodies into water were solved, particularly the problem of vertical submersion of a panel, cone, sphere and other bodies. These results brought about the development of the theory of gliding of long bodies, which was based on the analogy of the motion of a fluid in transverse planes during gliding and rapid entry of a body into water (G.V. Logvinovich, V.A. Sokolov, L.I. Tikhonov).

Systematic experimental investigations of submerged wings aided in establishing the principle derived in our country, of the stabilization of craft due to the decrease in lift of the wings in approaching the free surface of the water, as well as the change in the wetted surface of the wings in passing the free surface of the water. These principles were realized successfully in designing the Soviet craft "Raketa", "Meteor", etc. /45

Industrial Aerodynamics. Numerous problems of aerodynamics relative to various branches of technology are being developed at TsAGI. Studies on the theory of hydrodynamic networks, which were begun by N.Ye. Zhukovskiy, S.A. Chaplygin and others, were continued after the War and brought up to engineering usage (L.A. Simonov, E.L. Blokh, S.M. Belotserkovskiy, A.S. Ginevskiy, B.M. Kiselev). An experimental study of plane profile arrays and models of axial compressors resulted in the constructed of an effective method for profiling stationary axial compressors and axial ventilators (S.A. Dovzhik, K.A. Ushakov, I.V. Brusilovskiy).

A method for aerodynamical calculation of centrifugal ventilators was proposed on the basis of systematic experimental studies (in the 30's and 40's) at TsAGI ventilators are being constructed for the metro in Moscow and other cities of the country, for the mining industry, and thermal electric power plants. Gigantic ventilators with diameter of 10-20 m are made according to the aerodynamic designs of the Institute for water-cooling towers, as are the multi-stage compressor of the first Soviet gas turbine system, and miniature (with diameter of 30-120 mm) axial, centrifugal and other ventilators used for cooling apparatus. Substantial

results were obtained in the theory of turbulent jets (G.N. Abramovich, A.S. Ginevskiy and others).

Strength and Stability of Aircraft Structures. The engineering science of the stability and strength of aviational structures began to be put together with the first practical steps of aviation, and in its development it introduced a large number of new divisions and methods in structural mechanics and the applied theory of strength, as well as mechanical aspects of determining the endurance of structures.

The development of problems of the stability of aircraft structures relating to the interaction of an elastic body with the air brought about the arisal of a particular division of applied mechanics, which was called aeroelasticity.
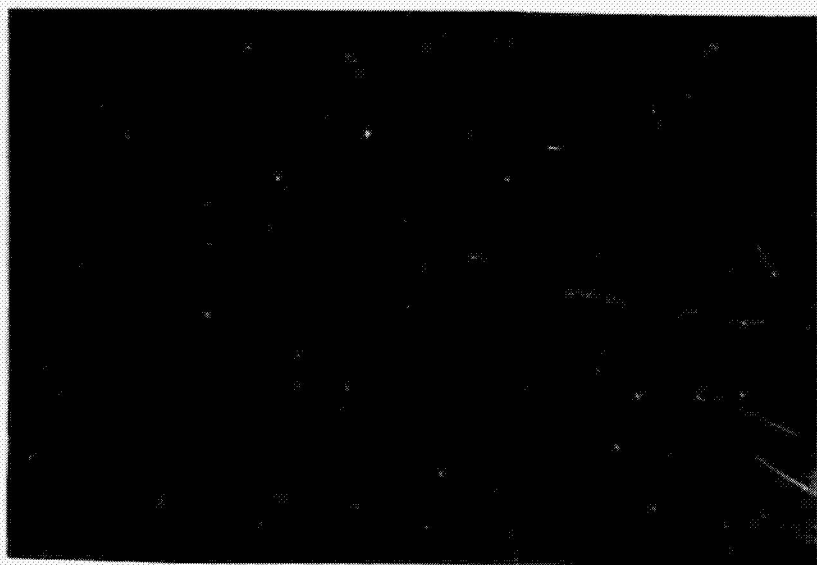
Bench Tests for the Strength of a Wing in an Aircraft
System.   /46

The need for establishing the calculational conditional and criteria for determining the requirements on strength and stability of structures which guarantee safe operations arose in connection with the specific conditions for designing and operating aircraft when the spectrum of external disturbances has a complex nature.

As a result, four divisions of the engineering science of the stability and strength of aircraft structures were defined: the strength norms, the aeroelasticity, the static strength and the endurance. The basic principles of these divisions were established at TsAGI.

Strength Norms. The first requirements on the strength of an aircraft were formulated in 1916, when N.Ye. Zhukovskiy and his pupils (A.N. Tupolev, A.A. Arkhangel'skiy, V.P. Vetchinkin and others) proposed a certain ordering of conditions for designing an aircraft in terms of strength. The data on the strength norms were

first published in 1926 and based mainly on the results of a few
flight tests and theoretical calculations (A.A. Gorainov, G.I.
Kuz'min). The arisal of strength norms which reflected the con-
nection between calculated G-loads and the purpose of the aircraft,
its weight and maximum speed more completely took place in 1934
(S.N. Shish'in).

As a result of special theoretical investigations and the study
of G-loads observed in flight during a maneuver and during its
travel through erratic air, with an evaluation of the possible ex-
tremal values, substantial corrections were introduced into the
strength norms. Due to this and subsequent studies considering the
multiplicity of aircraft-operation conditions, the strength norms
were converted from a set of a number of rules constructed on the
basis of experimental data into an engineering discipline based on
the theoretical and experimental results of general and applied
mechanics, which allowed a reliable determination of the calculated
conditions for strength of an experimental aircraft (A.I. Makarev-   /47
skiy, T.A. Frantsuz, I.I. Eskin, A.D. Kaluzhnin and others).

Water Channel

A large number of studies was connected with the development
of methods for determining the dynamic reaction of an elastic air-
craft to external excitation (N.N. Korchemkin, B.D. Frank, T.G.
Vasil'yeva, V.N. Chizhov, Yu.A. Stuchalkin), as well as methods for
estimating the statistical probability of the entire loading spec-
trum (T.A. Frantsuz, V.L. Raykher, A.M. Yershov and others).

Aeroelasticity. The problems of aeroelasticity became par-
ticularly important in the 30's in regard to the increase in flight
speed of aircraft. The disadvantageous ratio between the rigid
structure and aerodynamic characteristics of aircraft units when
a certain speed was reached (critical) can cause a dynamic loss
in stability of an elastic structure - a phenomenon which has been

called "flutter". A very rapid increase in sustained oscillations, which is characteristic of flutter, usually resulted in the disintegration of an aircraft in the air.

The theory of this complex phenomenon was developed at TsAGI (M.V. Keldysh). It showed that, for non-conservative mechanical systems with distributed parameters, an equivalent description of the oscillations was possible with equations for a finite number of discretely specified forms (degrees of freedom) with the subsequent use of the Bubnov-Galerkin method for integration of the equations. The possibility of using stationary aerodynamics for determining the aerodynamic forces acting on an oscillating wing was also demonstrated. Some scientists at TsAGI proposed a practical method for determining the critical method for determining the critical flutter velocity, which was widely used in aircraft designing (M.V. Keldysh, Ye.P. Grossman, Ya.M. Parkhomovskiy, L.S. Popov). A practical method of determining the critical flutter velocity of the rotating blade of a helicopter in the field of centrifugal forces was also developed later (M.S. Galkin, A.V. Nekrasov, V.D. Il'ichev and others). At the present, the problem of flutter is being solved theoretically on the basis of the Bub- /48 nov-Galerkin method and concentrated masses, with a wide-spread usage of electronic-computer technology in both cases (S.P. Strelkov, N.N. Dorokhin, Ye.I. Sobolev, V.G. Bun'kov, A.F. Minayev and others).

For a practical solution to the problems of aeroelasticity, the experimental method of determining the critical flutter velocity on dynamically similar models in wind tunnels is very important; the works of L.S. Popov, N.V. Al'khimovich, B.A. Kirshteyn, V.V. Lys-chinskiy and others had great significance in the development of this method.

Static Strength. The beginning of studies in the field of static strength was connected with the development of problems in the structural mechanics of an aircraft and the origination of the first courses in aircraft strength (V.P. Vetchikin, A.M. Cheremukhin, G.G. Rostovtsev), as well as the construction of the theory and engineering methods of testing the strength of the free-lifting wing of a monoplane (V.N. Belyayev). The idea of the structure of a wing as a unit boom operating on deflection and torsion was proposed on the basis of the method of determining the static strength. In determining the lifting capacity of a structure, the reduction coefficients were taken into consideration; due to this, the entire section of a wing could be reduced to a fictitious material with a unit modulus of elasticity obeying the Hooke law all the way to disintegration.

Methods of designing the wing of a monoplane and single propulsion elements in it were subsequently developed (A.Yu. Romashev-skiy, G.S. Yelenevskiy, V.F. Kiselev, A.A. Umanskiy, R.A. Adadurov, L.I. Balabukh, I.A. Sverdlov and others), and designs were developed

for sweptback and delta wings (V.F. Kiselev, V.F. Kut'inov, I.A. Sverdlov, I.F. Obraztsov, V.M. Frolov and others), as well as fuse-lages (P.M. Znamenskiy, V.M. Strigunov, Yu.G. Odinokov, G.N. Rudykh, S.I. Galkin). Great attention was also given at the Institute to the problems of the strength of aircraft structures at high tem-peratures (V.F. Kut'inov, A.A. Belous, A.N. Baranov, V.M. Marchenko, G.N. Zamula and others).

Impact and Submersion of a Disk into Water. On the Left - Disk at the Moment of Impact; on the Right - Submersion (A Cavity is Formed Behind the Disk).

Endurance. A number of studies in this field, carried out even in the 30's and 40's, were connected with the develop-ment of the necessary recommen-dations on the struggle with vibrations (I.V. Anan'yev, N.P. Serebryanskiy, P.G. Timofeyev, A.I. Pankratov and others). These studies aided in decreas-ing the level of vibrations on an aircraft from the effect of the rotor-motor group, thus making the problem of endurance determinant only for a small number of structural elements.

However, the problems of vibrations remained particularly important for the endurance of propellers. At the present, the theoretical and experimental basis for solutions to these pro- /49 blems can be found in the works of scientists of TsAGI (D.Yu. Panov, A.I. Pozhalostin, P.M. Riz, S.A. Tumarkin, G.M. Fomin).

The problem of endurance has again arisen at the present stage. It has been established that the so-called irregular static recurr-ing loads (N.I. Marin) are of determinant value for the endurance of an aircraft structure. At the same time, the duration of the operation of an aircraft has been lengthened, and the reserve of static strength has been decreased in connection with a precision of the strength norms. The use of high-resistance materials has increased the tolerance of a structure to concentrated stresses. All this has given the problem of aircraft endurance great acute-ness, particularly in connection with the wide-spread usage of helicopters.

Many studies of TsAGI treat the problems of the endurance of aircraft structures and the development of the necessary recommenda-tions (I.V. Anan'yev, N.I. Marin, A.F. Selikhov, A.Z. Vorob'yev, L.N. Yekimenkov, and others).

The theoretical and experimental studies carried out at TsAGI

are an important contribution to the development of our science.
The results of these profound investiga-
tions and searches always reach direct
introduction into practice. This style
is characteristic of the TsAGI school
founded by N.Ye. Zhukovskiy and S.A.
Chaplygin and thie talented disciples
and followers.

The achievements with scientific
thought have found fulfillment in our
aircraft, helicopters and rockets, pro-
duced on large scalt under the direction
of our outs`anding designers.

The new scientific-research insti-
tutes organized on the basis of divisions
and laboratories of TsAGI have a sub-
stantial effect on the development of the
corresponding branches of aviational
science and technology: Aircraft Material
Construction (VIAM), Aviational Motor
Construction (TsIAM), and Hydro-Machine
Construction (VIGM).

One of the First In-
dustrial Electric Wind
Plants of TsAGI, with
Power of 100 KW, Con-
structe   n 1935 near
Balakl   .

The merits of the TsAGI collective
are highly esteemed by the party and
government. The Institute has been
awarded the Order of Lenin, the Order of
the Red Banner, and the Order of the
Worker's Red Banner, a monument, the ap-
proval of the Central Committee of the Communist Party of the Soviet
Union on the 50th anniversary of the Great October Socialist Revolu-
tion, the Presidium of the Higher Council of the U.S.S.R., the Coun-
cil of Ministers of the U.S.S.R. and the All-Union Central Socialist
Party of the Soviet Union.

Ahead - new problems which will bring abou a vigorous develop-
ment in aviation and space technology. The great attention and care
of the party and government with aviational science and technology
is the insurance of their further undeviating perfection.

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